وزارة التعليم العالي
والبحث العلمي
جامعة الانبار
كلية العلوم/ قسم الفيزياء

اسم المادة: الليزر/2

المستوى الدراسي: الدراسات الأولية

المرحلة: الثالثة

المحاضرة الثانية عشر:

عنوان المحاضرة: قدرة وخطط الضخ

مدرس المادة

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Physics 571 Lecture #10

1 Three and Four Level Laser Schemes

As we saw in the previous lecture, the rate equations for level transitions in a two-level system are

$$\frac{dN_1}{dt} \rightarrow \dot{N}_1 = A_{21}N_2 - B_{12}\rho(\nu)N_1 + B_{21}\rho(\nu)N_2, \tag{1}$$
$$\frac{dN_2}{dt} \rightarrow \dot{N}_2 = -A_{21}N_2 + B_{12}\rho(\nu)N_1 - B_{21}\rho(\nu)N_2$$

We will consider N_1 and N_2 to be the number of atoms per volume in each of the two states. The energy per volume in the light field with frequency ν is $\rho(\nu)$. These equations show us how the number of atoms in each state will increase or decrease, depending on the light field and the current number of atoms in each state. Notice that $\dot{N}_1 + \dot{N}_2 = 0$, so $N_1 + N_2$ is constant. We'll call this constant N_T, the total number of atoms per volume in the system.

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حصل تغير في الذرات

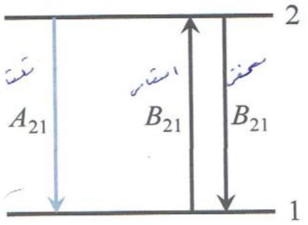

Figure 1: Two-level system.

In our last lecture, we showed that because the rate of stimulated absorption and emission are identical, we cannot achieve a population inversion (i.e. $N_2 \geq N_1$) merely by supplying a lot of photons at the transition frequency. We will need a different manner of increasing N_2 if we want to make a laser amplifier. The simplest way of doing this is called a three-level scheme. Figure 2 shows such a scheme, which involves a third energy level.

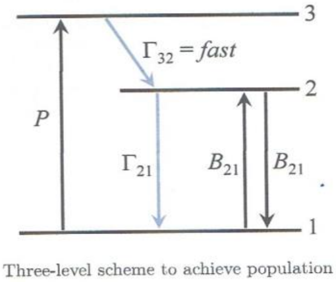

Figure 2: Three-level scheme to achieve population inversion.

As depicted in Fig. 2, some external 'pump' promotes electrons to an excited state (level 3), whereupon the electrons quickly decay to level 2. For simplicity, we will consider the decay rate Γ_{32} to be infinitely fast. We have changed letters from A_{32} to Γ_{32} to emphasize that these transitions can take place in other ways besides the spontaneous emission of a photon. For example, the transition could be assisted by collisions or vibrations. The pump could be, for example, an input flux of photons with energy $h\nu_{31}$. The rate equations for the three-level scheme are

$$\dot{N}_1 = -PN_1 + \Gamma_{21}N_2 + B_{21}\rho(\nu)(N_2 - N_1), \quad \text{(3 level)} \tag{2}$$
$$\dot{N}_2 = PN_1 - \Gamma_{21}N_2 - B_{21}\rho(\nu)(N_1 - N_2).$$

The only difference from Eq. 1 is the introduction of the pump rate P. We do not include an equation for $\dot{N}_3$ since there never builds up any population in state 3, by virtue of the fast transition directly into state 2. Notice again that we have $\dot{N}_1 + \dot{N}_2 = 0$, so $N_1 + N_2 = \text{const} = N_T$.

We now consider the steady state solution to Eq. 2. This means that $\dot{N}_1 = \dot{N}_2 = 0$. The solution is

$$PN_1 - \Gamma_{21}N_2 - B_{21}\rho(\nu)(N_2 - N_1) = 0, \quad \text{(3 level, steady state).} \tag{3}$$

We can simplify this a little by assuming a *small signal* scenario where the light $\rho(\nu)$ is very weak, meaning we can neglect the term involving it in the previous equation. In that case, we have

$$PN_1 - \Gamma_{21}N_2, \tag{4}$$

and the solution is

$$N_2 = \frac{P}{\Gamma_{21}}N_1. \quad \text{(3 level, steady state, small signal)} \tag{5}$$

We would like to express N_2 in terms of the total number of atoms per volume, so we $N_1 + N_2 = N_T$ in Eq. 5 to get

$$N_2 = \frac{P}{\Gamma_{21} + P}N_T, \tag{6}$$

$$N_1 = \frac{\Gamma_{21}}{\Gamma_{21} + P}N_T, \tag{7}$$

$$N_2 - N_1 = \frac{P - \Gamma_{21}}{P + \Gamma_{21}}N_T, \quad \text{(3 level, steady state, small signal)} \tag{8}$$

where the last equation is called the population inversion. If we want to have laser amplification, we need more atoms in the excited state than in the ground state, or $N_2 > N_1$. We see that this will be the case if $P > \Gamma_{21}$. The pumping must be strong enough to overcome the decay rate Γ_{21} in order to put more than half of the atoms in state 2 and to achieve laser amplification. As a side note, the injected power necessary for a given pump rate is given by

$$\frac{\text{Power}}{V} = h\nu_{31}PN_1. \quad \text{(3 level, steady state, small signal)} \tag{9}$$

Finally, we discuss a four-level scheme as depicted in Fig. 3. The appropriate equations are

$$\dot{N}_0 = -PN_0 + \Gamma_{10}N_1, \tag{10}$$
$$\dot{N}_1 = -\Gamma_{10}N_1 + \Gamma_{21}N_2 + B_{21}\rho(\nu)(N_2 - N_1),$$
$$\dot{N}_2 = PN_0 - \Gamma_{21}N_2 - B_{21}\rho(\nu)(N_2 - N_1).$$

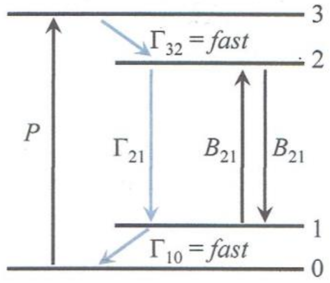

Figure 3: Four level scheme to achieve population inversion.

As before, we have $\dot{N}_0 + \dot{N}_1 + \dot{N}_2 = 0$, which implies (معنى) $N_0 + N_1 + N_2 = \text{constant}$.

Again we will pursue (نسعى) a steady state solution ($\dot{N}_0 = \dot{N}_1 = \dot{N}_2 = 0$). We will assume small signal so that terms with $\rho(\nu)$ can be neglected. It is left as an exercise to show that (CH-W)

$$N_0 = \frac{\Gamma_{10}\Gamma_{21}}{\Gamma_{10}\Gamma_{21} + \Gamma_{10}P + \Gamma_{21}P} N_T \tag{11}$$

$$N_1 = \frac{\Gamma_{21}P}{\Gamma_{10}\Gamma_{21} + \Gamma_{10}P + \Gamma_{21}P} N_T \tag{12}$$

$$N_2 = \frac{\Gamma_{10}P}{\Gamma_{10}\Gamma_{21} + \Gamma_{10}P + \Gamma_{21}P} N_T \tag{13}$$

The population inversion equation is

$$N_2 - N_1 = \frac{P(\Gamma_{10} - \Gamma_{21})}{\Gamma_{10}\Gamma_{21} + \Gamma_{10}P + \Gamma_{21}P} N_T. \quad \text{(4 level, steady state, small signal)} \tag{14}$$

مع خلاف

We see that a population inversion (i.e. $N_2 > N_1$) occurs if $\Gamma_{10} > \Gamma_{21}$. In contrast with the three-level scheme, the four-level inversion condition does not depend on the pump power P. Even a very week pump can achieve a population inversion in a four-level scheme, which is a big advantage. The only essential ingredient (المكون الأساسي) is that electrons need to fall out of level 1 (via Γ_{10}) faster than they fall into level 1 (via Γ_{21}). This is determined by the material, not external conditions.

يتم تحديدها ظروف

ع الحافز تبدله $N_1 = \frac{R_2}{A_{10}}$

فما في ترتيب $\Rightarrow$ from(12) $\Rightarrow$ ~~$N_1 = (\frac{P}{\Gamma_{10}} + \frac{\Gamma_{21}}{\Gamma_{10}} \frac{\Gamma_{21}}{P}) N_T$~~ ~~$\Gamma_{10} > \Gamma_{21}$~~ ~~$\frac{\Gamma_{21}}{\Gamma_{10}}$~~

~~$N_2 = (\frac{P}{\Gamma_{10}} + N_T P$~~

from(12) $\Rightarrow$ $\frac{P}{\Gamma_{10}} N_t$ لكن لما في ع شاح معادلة ١٢ يميل لـ $\Gamma_{10} > \Gamma_{21}$

كذلك الـ Γ_{21} يميل لـ قليل مبقى نشتغل

المصادر:

1- فيزياء الليزر – سهام عفيف قندلا

2- Introduction to Laser Physics 1st Edition- K. Shimoda

3- Basics of Laser Physics: For Students of Science and Engineering. (Graduate Texts in Physics) 2nd Edition.